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ABSTRACTS (PH D THESIS)

Miniaturization and Integration of Measurement Systems for Space Electromagnetic Environments

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Our exploitation of space is increasing and space systems such as GPS and climate satellites have become indispensable in our lives. It is hence very important to understand physical phenomena that occur in space. Space is filled with collisionless plasmas generated by the solar wind and the ionized upper atmosphere. The interaction between the solar wind and the Earth's magnetism forms the region called the magnetosphere. Space plasmas show different characteristics in the solar wind and the magnetosphere. The magnetosphere is divided into several regions depending on the plasmas' characteristics. The radiation belt region is the part of the magnetosphere that lies typically at geocentric distances of around 2 to 4 Earth radii. Highly energetic plasmas of protons and electrons exist in the radiation belts and can negatively influence space systems and human health. However, the mechanism of the generation and disappearance of the radiation belts is not yet clearly understood.

Plasma waves are an important physical phenomenon for understanding the behavior of space plasmas since the kinetic energy of the plasmas is transferred through the plasma waves. The phase of a plasma wave is related to the plasma's velocities and is important in the interaction between plasma waves and particles. The present thesis focuses on instruments for investigating plasma waves and wave--particle interactions.

A plasma wave consists of only an electric field or electromagnetic field. Sensors for plasma waves include dipole antennas for the electric field components and search coils or loop antennas for the magnetic field. The signals detected by the sensors are input to the electronics of the receiver for signal processing and data transmission through the telemetry. The electronics of the plasma wave receiver has been highly integrated and miniaturized by replacing analog components with digital hardware and software. This has been very effective for integration, though there is a trade-off between power consumption and processing speed. However, analog electronics are still used at the front-end of the receiver due to high performance requirements i.e., low noise, high sensitivity, wide-dynamic range, and wide-band frequency. Recently, multiple exploration missions have been planned and high performance miniaturized analog electronics would greatly benefit these missions.

In this thesis, the analog electronics for plasma wave observations are developed with application specific integrated circuit (ASIC) technology in order to greatly reduce the size and mass of the instruments. A plasma wave receiver can be either a waveform receiver or a spectrum analyzer. A waveform receiver observes instant electric and magnetic fields while a spectrum analyzer provides the time evolution of the intensity in each frequency band. Only a waveform receiver contains phase information of the plasma waves. The target components for miniaturization of the waveform receiver are a band-limiting filter, a variable gain differential amplifier with low, medium, and high gains, and an anti-aliasing filter. The Gm-C filter is a commonly used active filter for communication front-end with low noise and can be applied to the band-limiting filter. A multi-gain differential amplifier is realized with switching resistors to obtain each appropriate gain. Since the anti-aliasing filter must be manufactured accurately, a switched capacitor filter is suitable. However, extra Gm-C filters are necessary in the front and back of the switched capacitor for noise elimination. The spectrum analyzer has an advantage in that it can provide an overview of plasma waves and their variations. The sweep frequency analyzer (SFA) is one type of spectrum analyzer which sweeps the observation frequency range finely. The SFA has poor time resolution and fine frequency resolution. The target SFA in the present thesis has an improved time resolution without losing frequency resolution. The SFA is a double super heterodyne receiver. Because of frequency conversion, unnecessary signals at image frequency is to be rejected. Thus, a frequency synthesizer, mixer, and band pass filter must be developed for the ASIC. These circuits for both receivers are tested after manufacturing and their

feasibility is evaluated.

The developed components are integrated into one chip. For the waveform receiver, a six-channel circuit of filters and amplifiers is laid on the chip. After the layout design, the chips are manufactured using the TSMC 0.25μ CMOS process. A circuit board is also designed for mounting the chip. A power supply, clock generator, divider, and six A/D converters are implemented on the circuit board. The area of the analog components is reduced to a twentieth the size of previously developed instruments.

Applications using the miniaturized plasma wave receiver are proposed. A sensor network for plasma wave observation is introduced, consisting of a distribution of several sensor nodes with small plasma wave receivers where observation data are collected at each node. This application can obtain the spatial distribution of plasma waves. The second application consists of a constellation of satellites, used to determine the position of the plasmapause with Faraday rotation. One satellite in the constellation actively emits radio waves of linear polarization. The other satellites receive the emitted radio waves with small wave receivers and detect the variation of the polarization direction from the expected value. The principle and system design of the satellites are discussed.

Moreover, a direct measurement system for energy transfer between plasmas and plasma waves is presented. The calibration of the waveform data and time correction for synchronization of the particle data with the waveform are described. The one-chip system is realized in the FPGA with real-time processing.